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Progress in Parallaxes at USNO

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Abstract. The accuracy of trigonometric parallaxes from the U.S. Naval Observatory (USNO) has continued to improve. An optical CCD camera is used regularly on the 61-inch telescope. It produces parallaxes with typical errors of ± 0.5 mas, and can reach ± 0.3 mas with some effort. The program provides distances, absolute magnitudes, and tangential velocities accurate to a few percent for many white dwarfs and low-luminosity red and brown dwarfs. Other classes of special interest being observed are planetary nebulae, cataclysmic variables, dwarf novae, and dwarf carbon stars. Some stars show residual perturbations from a close companion, and the astrometric orbital solutions indicate a brown dwarf or (in a few cases) a possible planetary-mass companion. In addition, a near-IR InSb camera is used for parallaxes of very red L and T brown dwarfs. We discuss the relationship of USNO and other programs, and the prospects for further progress.

1. Introduction

The USNO began observing trigonometric parallaxes of stars with the Strand 1.55-m telescope in Flagstaff after it came into operation in 1963. The use of CCD detectors for parallaxes since 1985, and IR detectors since 2000, has greatly improved the astrometric accuracy and limiting magnitude over photographic plates (at USNO and other observatories, e.g. Dahn 1997). The astrometric data are used to test detectors for precision and stability and to evaluate atmospheric distortions. Improved CCD quality and attention to data quality control continue to contribute to the astrophysical goals: the accuracy of parallaxes now exceeds the mean Hipparcos accuracy, typically by a factor of 2 to 3. Figure 1 shows improvement in the parallax error from USNO publications, and shows the Hipparcos error for comparison.

2. Progress in Precision and Accuracy

Images are taken with a Tektronix 2Kx2K CCD with a field size of 11 arcminutes. Filters similar to R, I, and z are used for program stars with R magnitudes from 12 to > 22, with exposure times usually a few to 40 minutes. Relative positions are measured with residuals typically 3 mas (0.01 pixels) in each coordinate in a single observation when the full field of the CCD is used; however, in fields with many reference stars, a smaller field (3-4 arcminutes) can be used, and residuals drop to typically 1-2 mas in a single observation. This CCD produces noticeably

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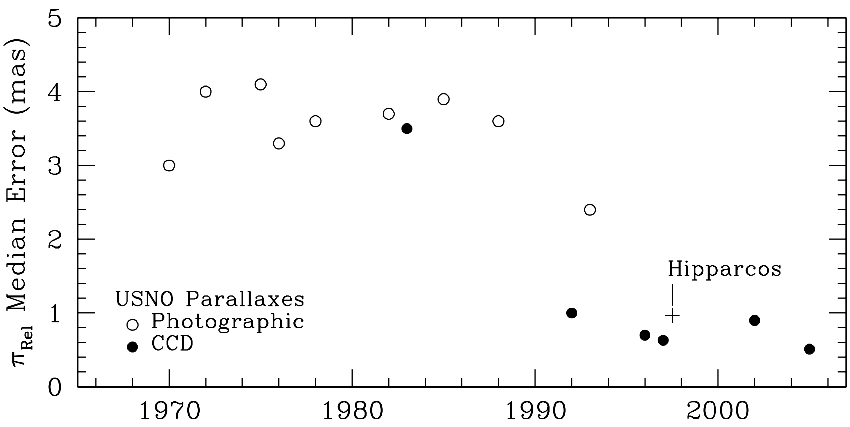

Figure 1. The historical improvement in the precision of relative parallax results in USNO publications. The data published in 2002 were early results for faint L and T dwarfs (Dahn et al. 2002). The data in 2005 are all 198 stars completed with the Tek2K CCD camera (paper in preparation). The Hipparcos result is shown for comparison.

better astrometry than the earlier TI 800x800 CCD described by Monet et al. (1992), even though the data processing is mostly the same as is described in that paper. The improvement comes primarily from the larger field size and greater full-well in the CCD pixels. Both factors allow more flexibility in choosing (and sometimes rejecting) reference stars and give more stable reference frames. After correction for differential refraction of red and blue stars, remaining residuals are probably caused by distortions from the atmosphere on arcminute scales and by imperfections in the detector. The number of reference stars and their extent on the sky, the exposure time, and the number of CCD frames acquired all affect the precision of a parallax solution. The precision normally continues to improve even after several hundred images have been acquired. Figure 2 shows the error for one typical star and for the ensemble of 298 stars that have at least one year of data taken with this CCD. Both panels of Fig. 2 show that the error does not decrease as fast as $\sqrt{N}$ owing to systematic effects (such as perturbations of reference-frame stars, or imperfections in the CCD), suggesting an additional error of 0.1–0.2 mas is being contributed to the parallax.

The parallax accuracy also requires knowing the correction for the parallaxes of the reference stars. This correction is typically 0.8–1.2 mas for the faint ($V \sim 18$) reference stars normally used. It is determined from photometry, usually with an uncertainty of 0.2–0.3 mas per field, except in fields at low galactic latitude where reddening complicates the analysis. Therefore, for most program stars, the error in the correction to absolute parallax is a minor (but not negligible) contribution to the total error.

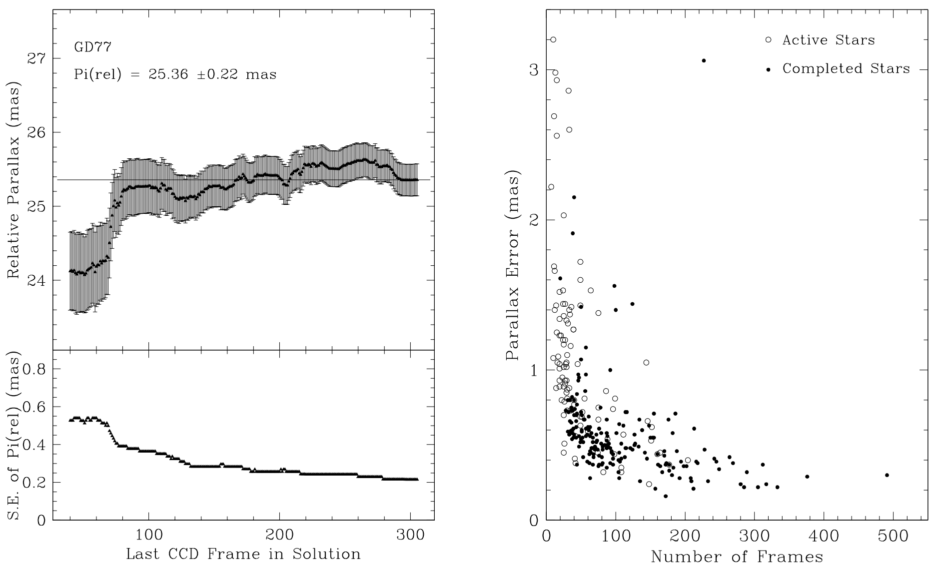

Figure 2. The improvement in precision of relative parallax results as the number of frames increases. The left panel shows the result for one typical star (a DA white dwarf) as frames are accumulated; jumps (near frame 70, for example) sometimes occur between observing seasons. The right panel shows the full set of stars.

3. Content of the Observing Programs

Stars are included in the optical CCD program to address a range of scientific questions (Dahn 1993). Stars that are currently active or recently completed fall into these general categories and science goals:

14 M dwarfs – ages, very low mass companions
30 L dwarfs – temperatures, space density
3 T dwarfs – temperatures, space density
13 K+M subdwarfs – kinematics, halo LF
70 white dwarfs – masses, evolution, LF
10 dwarf carbon stars – kinematics and populations
10 planetary nebulae – PN distance scale, space density
9 cataclysmic variables – understand peculiar types

Five cool (M and L) dwarfs and two white dwarfs have perturbations from an unseen companion – several of the companions are probably brown dwarfs and three could be massive planets, most are previously unknown.

The IR program employs an astrometrically-optimized camera (Fischer et al. 2003) using a Raytheon 2048 x 2048 InSb detector which provides a 6.2 x 6.2 arcmin field of view. This program began in September 2000 with 40 objects, split approximately evenly between L and T dwarfs. Observing procedures and preliminary results are described by Vrba et al. (2004). Continued observa-

tions are reducing the parallax errors from a median value of 3.6 mas in the preliminary results of Vrba et al. to 2.2 mas now. Stars currently on the IR program include primarily mid-L, late-L, and T dwarfs that are very faint at optical wavelengths and are observed more efficiently at IR wavelengths:

26 L dwarfs – temperatures, space density
32 T dwarfs – temperatures, space density

The IR program may be expanded to approximately 75 objects in the near future, with continued emphasis on late-L and T dwarfs.

4. Relationship to Other Programs

Little astrometric output will come from space missions soon – HST is under pressure to complete other science, FAME and DIVA will not fly, Kepler covers a limited area of sky, SIM and GAIA are well off in the future. Therefore, ground-based astrometry gives the only chance for parallax work for at least the next decade. Present programs including STEPS (Pravdo et al., 2005), RECONS (Henry et al., 2005), and USNO have sets of specific targets now going well beyond Hipparcos in accuracy and limiting magnitude. Pan-STARRS will have the advantage of working in survey mode, and has the potential to take over much of this work if funded for more telescopes; LSST has the potential to reach similar goals. However, the USNO and other similar programs will continue to reach highest accuracy for selected targets, and enable the study of very cool (and optically faint) T dwarfs.

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